The Effect of Illumination on Peripheral Vision

BY

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THE EFFECT OF ILLUMINATION ON PERIPHERAL VISION [1]

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INTRODUCTION

I. Problem.—In a cluster of recent studies[1] in peripheral vision, we find the statement that peripheral stimuli, which are themselves subliminal as regards color, may under favorable conditions induce colored after-images. These anomalous after-images are said to appear most often under conditions of intense illumination, with the stimuli shown upon a white background. On account of the theoretical importance of this statement, it was thought worth while to repeat the experiments. With this end in view, certain experiments were performed in the Cornell Laboratory by Titchener and Pyle.[2]

[1] H. B. Thompson and K. Gordon: A Study of After-Images on the Peripheral Retina, *Psychol. Rev.*, XIV, 1907, 122-167. G. M. Fernald, The Effect of the Brightness of Background on Color in Peripheral Vision, *Psychol. Rev.*, XII, 1905, 386-425; *ibid.*, XIV, 1908, 25-43; also *Psychol. Monographs*, X, no. 3, 1909.

[2] E. B. Titchener and W. H. Pyle, On the After-Images of Subliminally Colored Stim., *Proc. Amer. Philos. Soc.*, XLVII, No. 189, 1908, p. 377.

The outcome was negative. It seemed, however, that the "most favorable conditions" required had not been secured; and further tests were therefore necessary.

The present study was undertaken largely for the purpose of furnishing such supplementary tests. It was thought, moreover, that further work might throw light on certain irregularities in Fernald's general results. We undertook, therefore, to repeat Fernald's experiments, with additional variations, under exactly duplicate conditions.

After our experiments had been completed and put in what then seemed final form, a paper appeared[3] in which Fernald's theses were attacked from a new direction. Rand and Ferree now declared that instead of selecting the most favorable conditions for her phenomena—colored after-images from colored stimuli sensed as colorless—Fernald had chosen the very worst. They were unable to confirm the results that she obtained in the Bryn Mawr and Chicago laboratories; *i. e.*, they failed (as a rule) to get the anomalous colored after-images, when a white background was used. On the other hand, they were able, if they used a black background, prefixation ground, and projection ground, to secure these anomalous after-images practically in every trial.

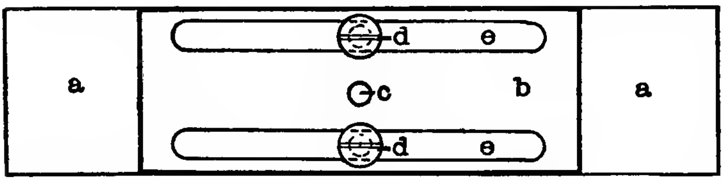
These new results—obtained in both direct and indirect vision—were startlingly at variance with what Fernald had found in her work with the black background; they were, moreover, the reverse of what our experiments had yielded. Indeed, they so flatly contradicted our findings that it seemed prudent to put them again to the test before advancing our own observations. It was evident that the method of Ferree and Rand differed in some details from ours—exactly in what ways, we could not fully make out from the (thus far) incomplete account of their method. We were told, however, that for the best results a black background, prefixation ground, and projection ground should be used; and that the white after-image of the black prefixation ground (fixated for 5 or 10 sec.) should be projected on the stimulus, which should itself be fixated for only 2-3 seconds. With these meagre directions to guide us, we repeated a large part of the work with the black background. The variations in method introduced, and the results obtained, will be given under the proper headings in the body of this paper.

[3] C. E. Ferree and G. Rand, Colored After-Images and Contrast Sensations from Stimuli in which no Color is Sensed, *Psychol. Rev.*, XIX, 1912, 195-239.

II. Apparatus.—The apparatus employed was, so far as seemed advisable, identical with that of Fernald. It consisted of a vertical two-sided campimeter similar to that pictured and described by her.[4] The stimulus frame was essentially the same as hers; but the screen which covered the stimuli, instead of being drawn to one side, was raised and lowered by a device which perhaps permitted greater rapidity of movement. When needed, an electric motor was suspended in the same position as the stimulus frame. The backgrounds used were platinum medium grey, white and black, and Hering velvet black. The stimuli were ten Hering colors: red, orange, orange-yellow, yellow, yellow-green, green, blue-green, blue, violet and purple; also Hering velvet black, and platinum grey.

Instead of a simple biting-board with triangular support, the Hering head-rest (with individual biting-boards) was used to

DIAGRAM OF ROTATION DEVICE ON BASE OF HERING HEAD-REST



a = depression in lower surface of base of head-rest.

b = movable brass plate, carrying pivot pin, *c*.

d, d = set screws in slots, *e, e,* for holding *b* in position.

keep the head in position. A special rotation-device[5] was arranged on the lower surface of the base, directly under *O*'s right eye (see diagram). The pivot pin *c* fitted into a hole in the table, which was in the plane of a perpendicular from the opening in the campimeter screen. For a given *O,* the plate *b* was so set that the distance from *c* to the center of the head-rest was exactly one-half the distance between the centers of *O*'s pupils. The modified head-rest thus provided for accurate determination of the position of *O*'s right eye (we used, as did Fernald, only the right eye, and stimulated only the left horizontal meridian of the retina), and in addi-

[4] *Psychol. Monog.,* X, No. 3, 1909, 16, 17. Details which were not clear to the writer were kindly furnished by Miss Fernald in correspondence.

[5] For this device we are indebted to Mr. W. S. Foster, assistant in the Graduate Laboratory.

tion for easy rotation to any desired angle. The adjustment once made was, therefore, constant for a given period of experimentation, and could easily be reproduced at subsequent sittings. It provided a further advantage, lacking in Fernald's arrangement, in that, after a single adjustment, *O* could fixate any number of points without turning his eyes.

The apparatus was set up in a large room (with light grey calcimined walls) on the top floor of the laboratory, directly beneath a 6 x 8 ft. skylight. The results reported were obtained (unless otherwise specified) on bright days, at hours when the sunlight shone directly on the skylight. A careful record of the illumination was kept, so as to ensure the most favorable as well as the most constant conditions. Most of the results were obtained in the spring, summer, and fall of 1911 and the spring of 1912. The tests made with the view of investigating the results of Ferree and Rand were carried on during the summer of 1912.

III. Observers.—Eight observers—the most highly trained in the laboratory—served in all or some of the experiments. Of these, Miss Goudge (G), Dr. Jacobson (J),[6] and the writer (D) were graduate students in psychology of two or more years' standing; Messrs. Boring (B) and Foster (F) were graduate assistants in the department; Mr. Tappan (T), an instructor in civil engineering, was carrying on graduate work in the department; Dr. Geissler (Ge) and Mr. Ruckmich (R) were instructors in psychology. All the observers possessed normal color vision. G gave warning that her experience in the Bryn Mawr laboratory had shown her to be deficient in sensitivity to after-images. R stated, at the outset, that he was highly suggestible to color.—In the last series of tests (summer, 1912), R, F, and Professor Baird of Clark University served as observers.

Method

I. General Procedure.—In general the method of procedure was essentially that of Fernald.[7] *O* was seated in a chair, whose height was adjustable, in front of the Hering head-rest, which was itself placed in front of the campimeter screen (as described above). The rotation-device was adjusted for the distance between his eyes; the Hering head-rest was set for the given observer (the settings were determined once for all, before experimentation was begun); *O*'s biting-board was

[6] J showed extreme liability to eye-strain and was, therefore, soon discarded.

[7] *Psychol. Monog.*, X, No. 3, 1909, 19, 20.

placed in position. The black velvet eye-shade was adjusted to cover *O*'s left eye. He then verified the accuracy of his position by making sure that a circle on the middle of the stimulus screen did not change its position, with reference to the opening in the campimeter screen, on rotation of the Hering head-rest. Inasmuch as the head-rest could be rotated to any angle, *O* was now prepared to take any fixation, without thereby incurring the slightest amount of eye-strain. There was, of course, no way of avoiding the eye-strain aroused by long-continued fixation; but the device gave us a signal advantage over Fernald's arrangement, which provided for only one position of the biting-board.

There was no further allowance of time for achromatic adaptation. Sometimes, however, *O*'s adaptation was tested by the presentation of grey stimuli. The regular experimental series (presentation of the ten colors and black and grey in haphazard order) then ensued. *O* took the desired fixation, and tapped on the table. *E* gave the signal "ready," and immediately raised the stimulus screen,[8] exposing the chosen stimulus. After an exposure of 5 seconds (determined by the stop-watch) *E* gave a signal "now," and, after a moment, lowered the stimulus screen over the stimulus. In case the color seen by *O* disappeared before the five seconds were over, *O* signalled by a tap to *E*, who immediately lowered the screen. *O* held his fixation until all traces of the after-image had disappeared, waiting, as a rule, some time longer for certainty. *O* was now required to report in full on the hue, tint, and chroma of both sensation and after-image. He was shown a duplicate of the small-sized Hering *Farbenkreis* and was asked to place the colors experienced among those of the Hering series; if a color fell between two adjacent colors of the circle, it was so designated, emphasis being given when possible to the predominant component. *O* was also required to note other experiences connected with the color, *i. e.*, number of recurrences and relative duration of after-images, changes in hue in either sensation or after-image, color seen during the fore-period of a given test, eye movement during prescribed fixation, eye-strain, inattention. For a number of experiments *E* carefully watched *O*'s eyes, so as to note the occurrence of perceptible eye movement. *E* kept a record of all such relevant data, as well as of the report proper. In case *O* reported a color during the fore-period, the time-interval was lengthened; otherwise, the next stimulus was presented two minutes (or more) after *O* removed his teeth from the biting-

[8] The prefixation period was thus minimal.

board; the interval was recorded by stop-watch, and the exact time was recorded by *E.*

II. Methods.—Two main lines of method (A and B) were laid out. In the first (A), the ten Hering colors and platinum grey and black were presented in haphazard order as stimuli. The backgrounds were platinum medium grey, Hering velvet black, and platinum white.

A 1. The first experiments were performed with the platinum grey as background and projection ground (*i. e.,* screen on which the after-image was projected). This background, it was thought, would be the most favorable for both sensations and after-images, and would therefore serve as a fairly easy introduction to the more difficult work with black and white backgrounds. Sets of results, at fixations from 20 to 90 degrees, were obtained (with some gaps) from five observers. In the first part (*a*) the Hering colors mounted on cards were used as stimuli. At the start they were presented to the observers, at fixations from 55 to 90 degrees (this was our interpretation of Fernald's "more peripheral points"), as long as any color was seen. This time, however, was found to be too long; the observers soon complained of eye-strain. The exposure time for all fixation-points was then arbitrarily fixed at 5 seconds (or less, if the color disappeared within that time). In the second part (*b*) certain Hering colors, mixed with varying amounts of black or white, were presented as stimuli. Some observations were also made (*c*) in which the individual after-images of Hering colors were projected successively on different backgrounds.

A 2. The Hering velvet black was next used as background. (*a*) Full sets of results (20 to 90 degrees fixation) were obtained with six observers for the ten Hering colors. (*b*) Observations were also made by three of these observers, for fixations from 60 to 90 degrees, with the black background and the platinum medium grey as projection ground.

A 3. The platinum white background was reserved until last, in order that the observers might have the advantage of a year's training. This background, it had been asserted, was the most favorable to "colored after-images from unperceived stimuli." To it therefore we devoted the most time, taking, with the white background and projection ground (*a*) some 1,700 observations from five observers (as compared with 650 for platinum grey and 1,100 for Hering black). The majority of the results were obtained at the more peripheral fixation points. Additional sets were taken under special conditions with (*a'*) the attention variously directed (*i. e.,* sometimes on the stimu-

lus, sometimes on the after-image) and with (a'') variations of the time interval between experiments. Results were also obtained (b) from two observers, with the white background and black projection ground. Only a few tests—because the method proved too fatiguing—were taken (c) in which the observer fixated the white ground for some time (5, 10, or 15 seconds) before exposure of the stimulus, thus mixing the dark after-image of white with the stimulus.

In the second part (B) of the problem, the aim was to determine (1) the *Urfarben* and (2) their limits for the different backgrounds. Mixtures of Hering red, blue, green, and yellow, and black and white were the stimuli. Our present procedure differed from that of A, in that we now presented a single stimulus continuously, starting at either 0 or 90 degrees fixation, and taking successive fixations to 90 or 0 degrees respectively. Our method was essentially that of Fernald.[9]

Results

General Interpretation of Tables.—Inasmuch as frequent use will be made of tables it may be well to give here a general interpretation of the symbols used. The colors are always indicated by their corresponding initials (R = red, OR = orange-red, BG = blue-green, BlG = bluish green, etc., of the Hering series). The symbols for two colors connected by a hyphen indicate a color the hue of which lies between the two hues indicated; if the one component is predominant the corresponding symbol is italicised. A line —— is used to indicate colorless sensations or after-images. The numerical subscripts under color symbols indicate the number of times of occurrence.

I. Effect of Background on Sensation

A. Changes in Hue

1. With Medium Grey Background

Table I gives a representative account of the course of the sensations from the ten color stimuli. It will be seen that here (as in the case of the other observers): (1) sensations from the red stimulus undergo little change from 20 degrees to 90 degrees of fixation, shifting only slightly toward orange; (2) with the orange we have a decided shift through orange-yellow practically to yellow; (3) orange-yellow becomes yellow at the extreme periphery; (4) yellow soon loses its slightly

[9] *Psychol. Monog.*, X, No. 3, 60.

greenish cast, but is otherwise constant; (5) yellow-green passes through greenish-yellow to yellow; (6) green shifts quickly toward yellow and is soon colorless; (7) blue-green passes through greenish blue toward blue; (8) blue is fairly constant; (9) violet becomes blue; and (10) purple passes through violet to blue. Thus red, orange, orange-yellow all shift (the amount depends roughly on the proportion of yellow in the stimulus) toward yellow; while blue-green, violet and purple shift toward blue. In both cases the green component

TABLE I

O=B

Grey Background.

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
90	—	Y? Y-OY	Y	Y	—	—	—	—	—	—
85	—	Y-OY	*OY*-O Y	Y	Y-GrY Y	—$_2$	—$_5$	B	B	B B? —
80	O R	Y-OY$_2$	Y	Y	Y-OY	—	B	B	B	—
75	*OR*-O OR	Y-OY	*O*-OY OY	Y *Y*-OY	Y	—	GrB	B	B	—
70	OR	*O*-OY	*Y*-OY	Y	Y	—	GrB	B	B	*V*-P
65	OR	O	Y	Y	Y	—	OY-O	B	B	P
60	OR-R	*O*-OY	OY	Y	Y	—	GrB-B	B	*B*-V	P-V
55	O$_2$	OY	*OY*-O	Y-OY	Y-GrY	YG	B-GrB	B	B	P
50	*OR*-R	O	*OY*-O	Y	Y-GrY	YeG	GrB	*B*-GrB	B-V	P
45	R	*OR*-O	O	Y	YG-Y	YeG	GrB	B	*V*-B	*V*-P
40	*OR*-R	O	OY-Y	Y	YG-GrY	YeG-YG	GrB-BG	B	*V*-P	P
35	R	O	Y-GrY	Y	GrY-Y	YeG	GrB	B$_2$	B	P
30	R-PR	O	OY-Y	Y	GrY-Y	G	BlG	B	*V*-P	P
25	R-PR	O	OY	Y	YG-GrY	YeG	BlG	B	V	P
20	OR	O	OY	*Y*-OY	YG-GrY	BlG	BG	B	*V*-P	P

tends to disappear first, before the red, a fact that we may reasonably attribute to the poorer saturation of the green.

2. With Hering Black as Background

Table II is typical of the course of the sensations from the ten colors, with the black background. (1) Red shows a rapid and pronounced shift toward yellow, becoming finally orange-

TABLE II

O=D | Black Background.

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
90	OY OY-O	OY-O OY	OY-O_2	OY_2	OY Y	—$_2$ Y	B-GrB GrB?	B-GrB_2 GrB-B	B-GrB B-V	GrB-B —
85	OY-O_2	O-OY	OY-O_2	OY O-OY	Y-OY	B? —	GrB-B GrB	GrB-B V	B GrB	GrB V
80	OY-O Y-OY O-OY	OY-O_2 OY	O-OY OY-O OY	OY Y-OY_2 Y	OY-Y_2 Y-OY	Y-OY Y	B GrB	B_2	B_2	B-V B GrB
75	O-OR OY-O	O OY	Y	OY-O OY	O-OY_2 OY	—$_2$	V? GrB	B_2 GrB	B B?	P-V GrB
70	O-OR OY-O	GrB	OY-O OY	O-OY Y-OY Y	OY Y-OY Y	—$_2$	B-V GrB	B_3	B_2	P+B BG
65	O-OR O	O-OR OY-O_3	OY-O Y-OY OY	OY-O OY Y	O-OY Y	OY-O —	BG GrB_2	B_3	B-V GrB-V	B+P P-PR
60	O-OR O	OY-O OY	OY-O Y	Y_2	Y-OY Y	Y —	BG-GrB GrB	B_2	B_2	B P
55	O-OY	OY-O	OY	Y	Y	Y	GrB	GrB	GrB	P-V
50	O-OY	OY-O	OY	Y	Y	Y	GrB	B	V-GrB	P-V
45	O	OY-O	OY	Y	Y	Y	GrB	B	B-V	P
40	O	O-OY	OY	Y	YG-GrY	GrY	GrB	B	V-B	P
35	O-OY	OY-O	Y	Y	YG-GrY	Y	BG	B	V-P	P
30	O-OR	O	OY	Y	YG	YeG	BG	B	V-B	P
25	O-OR	O	Y	Y	YG	G	BG	GrB	V-B	P
20	O	OY-O	OY	Y	GrY?	BlG	BG	GrB	GrB	P-PR

yellow at 90 degrees; (2) orange follows a similar course; (3) orange-yellow is fairly constant, showing a slight shift, in some cases, toward orange (with D and R), but generally to yellow; (4) yellow is also fairly constant, though it loses its greenish cast and shifts as a rule toward orange-yellow; (5) yellow-green passes rapidly through greenish yellow to yellow; (6) green soon becomes yellow, which is seen only intermittently at the extreme periphery; (7) blue-green quickly shifts to greenish blue and, with some observers (B and T), to blue; (8) blue is intermittently blue or greenish blue throughout the series; (9) violet shifts gradually toward blue, as also (10) does purple. Thus, the change with red, orange, orange-yellow, yellow-green, and green stimuli is toward yellow; while that of blue-green, violet and purple is toward blue.

3. With the Platinum White Background

Table III has been selected as fairly representative of the results obtained with the white background and projection ground. It shows the general trend of the colors. With this background, however, there is greater variability in the observers, and also in the results for a single observer, than with the other two backgrounds. Because of this variability, special additional tables IV-VIII have been prepared, which represent respectively the results from red, orange, orange-yellow, yellow, and yellow-green, for all the observers. (1) Red is fairly constant, changing only slightly in the direction of yellow; (2) orange is almost as constant, but shifts somewhat toward red; (3) orange-yellow changes also toward red, though it only occasionally shifts beyond orange; (4) yellow soon loses its decidedly greenish cast and changes in the direction of red; it almost never, however, shows a shift beyond orange; for G and B it is practically constant, and for the other observers it shifts generally only to orange-yellow; (5) yellow-green passes through greenish yellow and yellow to orange-yellow; for B it then shifts almost to orange; for F it becomes even more reddish; for the others (D, G, and R) it practically remains slightly on the yellow side of orange-yellow; (6) green shifts through yellowish green, yellow-green, and greenish yellow to yellow; it is then usually colorless, but is sporadically seen as orange-yellow, orange, or a color between orange and orange-red; (7) blue-green changes to greenish blue or blue; it is even occasionally seen on the periphery as bluish green; (8) blue is fairly constant; (9) violet becomes blue for all except F, for whom it is sometimes violet; (10) purple likewise becomes blue for all except F, for whom it is

TABLE III

O=F White Background.

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
90	—	—	—	—$_2$	—	—	B-V B?	*B*-(V) V	V$_2$ —$_2$	—
85	—	—	—	?-Y-?	—$_2$	—$_2$ OR-O	—$_4$ B V	*B*-V *V*-B	—	—
80	—$_2$	OR O-OR	O-OR$_3$ O$_2$	OY? —	—$_3$ *O*-OR O-OY	—$_3$	— B	B$_2$ V-B *V*-P$_2$	— B? V$_2$?	B? V$_2$
75	— OR O-OR$_2$ O?	O-OR$_2$	O-OR O	O-OR	O-OR	— OR?	B V-B	GrB B-GrB V-B	V V? BG	V? B-BG?
70	OR	O-OR	OY-O	*GrY*-Y	—$_3$ OY-Y$_2$? Y?	—	*B*-V *V*-B	*V*-B BG	*V*-B GrB	—$_3$ *B*-V$_3$ V
65	—	*OR*-O	OY-O	?-Y-?	OR-O$_2$ *OY*-O O$_2$ GrY or OY	OY-O	V	V	V	—$_4$
60	O-R	*OR*-O	O-OR	O-OY	OY or GrY-YG	—$_{16}$	B-GrB	B-GrB	V	V$_2$ *V*-P
55	OR	O-OR	O-OR	Y-OY	?-Y-?	—	B	B	B	V
50	OR-O	*OR*-O	OR-O	*GrY*-YG	*YG*-GrY	—	GrB	V	V	P-V
45	OR	O-OR	O *O*-OR	*O*-OY	YG-YeG	YeG	B	V	*V*-P	*V*-P
40	OR	OR	*O*-OY	*OY*-Y	*YG*-GrY	*G*-BlG	*B*-GrB	B	V-B	P
35	OR	*OR*-O	*O*-OR	*Y*-OY	YG	*YeG*-YG	*BlG*-BG$_2$	B	V	*V*-P
30	OR	O-OR	OY	OY	YG	YeG	BG	B	V	*P*-V
25	*R*-OR	*O*-OR	O-OY	Y	YG	*G*-YeG	*BlG*-BG	B	*V*-B	P
20	*OR*-R$_2$ R	OR-R$_2$ OR	OY-O$_2$ OY	YG-GrY YG *OY*-Y	YeG	G YeG	BlG	B	V	P
5	R	*O*-OR	OY	Y	YG	G	*BlG*-BG	B	*B*-V	P
0	R	O	OY	Y	YG	G	BlG	B	V	P

TABLE IV

Stim.=R White Background

Fix'n. °	Observers				
	B	D	F	G	R
90	—		—		—$_3$
85	O —	—	—	—	—$_4$
80	—$_2$		—$_2$ B?	B	OR —$_5$
75	*V*-B —	R R?$_2$	— OR O? O-OR$_2$	R?	OR OY
70	O —$_3$		OR$_3$	—	— O
65	R	R R??	—	O	OR O
60	*O*-OR O_2 *O*-OY*		O-R	Y?$_2$	V
55	O-OR		OR	R	O_2
50	OR		OR-O	R	R
45	R		OR	OR	R
40	*PR*-P		OR	*OR*-R	R
35	R-PR		OR	OR	R
30	R		OR	OR	R
25	*R*-OR		R-OR		R
20	R		OR-R *OR*-R R	R	OR
5	R-OR	R	R	*R*-OR	R
0		OR	R	R-OR OR	*OR*-R OR

TABLE V

Stim.=O White Background

Fix'n. °	Observers				
	B	D	F	G	R
90	—		—$_2$		—$_2$
85	—$_2$	—	—	—	—$_5$
80	—$_2$		O-OR OR	—	P —$_4$
75	— R	O	O-OR$_2$	O or OR? —	O Y
70	OR$_2$ R		O-OR *OR*-O	OY	O — OR
65	OR-O	R	*OR*-O	O	OR O
60	OR-O		*OR*-O	O	O
55	O-OR	O	O-OR	O	O
50	OR-O		OR-O	*OR*-O	OR
45	R		O-OR	O-OR OR	O
40	R-PR R		OR	O	R
35	R		*OR*-O	*OY*-O	OR
30	R-OR		O-OR	*O*-OY	R
25	OR		*O*-OR		R
20	O OR		*R*-OR$_2$ OR R-OR YG?	O	O
5	*OR*-O	O	*O*-OR	O$_2$	O
0		O-OR OR-R	O$_2$	O	O$_2$

TABLE VI

Stim.=OY White Background

Fix'n. °	Observers				
	B	D	F	G	R
90	—		—		—$_3$
85	— O	?	—	—	—$_3$
80	—$_2$		O-OR$_3$	—$_2$	Y P —
75	— O	Y OY-O	*O*-OR O	*OY*-Y OY	OY — OY-Y
70	— O		OY-O	O *OR*-O	OR O
65	O	O	OY-O	OY	OR *OY*-O
60	O_2		O-OR	Y	O
55	OY-Y	*OY*-O	*O*-OR	*OY*-O	O
50	O		*OR*-O	*OY*-O	OR
45	*O*-OR		O *O*-OR	*Y*-OY	OR
40	O		*O*-OY	*OY*-O	O
35	O		*O*-OR	OY	OY
30	OY		OY	OY *O*-OY	O
25	O-OY		O-OY		O
20	OY		OY OY-O_2	OY	OY
5	OY	OY_2	OY	OY	OY
0		OY	OY	OY_2	OY_2

TABLE VII

Stim.=Y White Background

Fix'n. °	Observers				
	B	D	F	G	R
90	— B		—$_2$		—$_3$
85	—$_2$	—	-Y-?	B? —	—$_3$ V
80	— Y		— OY?	Y	Y_2 — O GrY
75	— O	Y-OY	O-OR	Y_2	Y GrY
70	Y —		*GrY*-Y Y	Y	O Y_2 —
65	*Y*-OY	OY_2	-Y-	Y	O Y
60	Y_2		O-OY	Y_2	O
55	Y	OY	Y-OY	Y	OY
50	*Y*-OY		GrY-YG	Y	OY
45	Y+OY		*O*-OY	Y	Y
40	OY-Y		*OY*-Y	*Y*-OY	Y
35	Y		*Y*-OY	Y Y-OY	Y
30	Y		OY	Y	Y
25	*Y*-OY		Y		Y
20	*Y*-OY *Y*-GrY		YG-GrY YG *OY*-Y	*Y*-GrY	Y
5	Y	Y	Y	*GrY*-YG	Y
0		Y	Y	*GrY*-Y *Y*-GrY	Y_2

TABLE VIII

Stim.=YG White Background

Fix'n. °	Observers				
	B	D	F	G	R
90	— R? B?		—		—$_3$
85	—$_2$	— Y	—$_2$	B or P?	—$_4$
80	—$_7$ R		—$_3$ *O*-OR O-OY	B?	—$_8$ Y
75	—$_2$	OR-O	—$_3$ O-OR O? O-OY Y	O	—$_{12}$ Y_3 P-R_6 O? Y or G
70	O-OY OY O —		OY-Y?$_2$ —$_3$ Y?	Y	—$_3$ O
65	OY	*OY*-Y	OR-O_2 O *OY*-O GrY or OY	Y	R OY
60	Y *OY*-O —		OY or GrY-YG	Y_2	O
55	Y	*Y*-OY	-Y-?	Y	OY
50	*GrY*-YG		YG-GrY	Y	—
45	YG		YG-YeG	Y	YG
40	YG		*YG*-GrY	GrY	YG
35	YG		YG	GrY	YeG
30	YG		YG	GrY-Y	YG
25	YG		YG		G
20	YG		YeG	GrY	YeG
5	YG-YeG	YG	YG	YG	YG_2
0		YG	YG	YG	YG *YG*-YeG

occasionally violet. Thus, red shows a very slight change toward yellow; orange, orange-yellow, yellow, and yellow-green change in the direction of red; green becomes yellow (possibly reddish); blue-green, blue, violet, and purple become blue.

4. Comparison of Results for the Three Backgrounds

a. Effect on hue

A comparison of the results for the different backgrounds shows that: (1) the effect on red is practically the same with the grey and the white grounds (a slight shift toward yellow); the shift toward yellow is much more marked with the black ground; (2) orange, orange-yellow, yellow, yellow-green, and green all shift toward yellow with the grey and the black grounds, and toward red with the white ground; (3) blue, blue-green, violet, and purple tend to become blue with all three backgrounds; blue-green and blue have, however, a slight tendency to appear greenish blue with the white background; and blue, violet and purple may change slightly toward violet with the black background.

b. Effect on limits for colors

The results give also a rough indication of the effect of background on the limits for the different hues. Table IX gives the estimated mean values for all observers, with each of the backgrounds, of the limits for (*a*) the 10 colors seen as such, and for (*b*) the 10 different colors seen (as Vorfarben). Considerable variation is shown. With the grey ground the order of extent of the colors is: (*a*) B, R and OY, O, Y, P, BG, V, G, YG; (*b*) Y, B, OY, O, R, V, P, BG, G, and YG. With the black ground the order is: (*a*) B, OY, Y, O and P, G, BG, R, YG and V; (*b*) B and Y, OY, O and P, BG, G, V and R, YG. With the white ground the list runs: (*a*) B, R, Y, OY, O and G, BG, V and P, YG; (*b*) B, R and O and Y, OY, P, V, BG, G, YG. The variations between (*a*) and (*b*) are obviously due in large measure to differences in chroma and tint of the colored papers. Comparing the three backgrounds, we find that results from the grey are in general intermediary between those from the black and those from the white. The white ground shows the widest limits for red, orange, and blue-green; the black for the other colors.

c. Comparison with Fernald's Results

The results obtained thus far differ in some details from those of Fernald. (1) Red with the white background is not "more carmine at the outer limits than at the center;" the tendency is rather for it to be, if anything, slightly more car-

TABLE IX

LIMITS FOR COLORS

Backgrounds

Stim.	*a*			*b*		
	Grey	Bk.	Wh.	Grey	Bk.	Wh.
R	70	35	75	70	50	80
O	65	70	45	75	70	80
OY	70	75	50	80	85	75
Y	60	85	70	90	90	80
YG	30	30	25	40	40	35
G	40	50	45	40	55	45
BG	50	45	60	45	50	60
B	85	90	80	85	90	85
V	45	50	35	65	60	60
P	55	70	35	60	70	70

mine at the center. (2) Orange-yellow and yellow show in general a less marked change toward red than in Fernald's results; her observers perceived orange-yellow as red as far out as 95 degrees; we seldom found it to change beyond orange; none of our observers saw yellow (as two of hers did) as red on the periphery. (3) Fernald gives no statement of results with yellow-green and blue-green, nor for green with the black background. (4) With the black background, violet and purple were not seen as such at the extreme periphery, as was the case with her observers; instead, they tend to shift toward blue.

5. Results of Mixing Black or White With Colored Stimuli: Grey Background

Different amounts of black or white, mixed with colored papers on an electric color mixer, were presented as stimuli at all the fixation points, with the grey background, in order that we might determine how far the results with different backgrounds might be duplicated with a single background, by actual measurable physical mixture of colors with light.

Samples of the results are shown in the form of graphs (1-4). In this case, a single color, mixed with black or white, was exposed successively at fixations from 90-0 degrees. (It was found, incidentally, that a saturated red stimulus tended to appear less red on the periphery, when rotated, than it had in general in the haphazard tests with cards; the results for red mixed with a light were, therefore, compared with those for the rotated, saturated red presented under the same conditions.) Red, orange, orange-yellow, and yellow-green, when mixed with black, show very much the same effect, from darkening, as results from the darkening of the stimulus by contrast with a light ground, or by superposition of a dark after-image on the stimulus. These colors appear more red at the periphery as the amount of black is increased; similarly they appear more yellow at the periphery as the amount of white mixed with the stimulus is increased. Blue, violet, and purple change toward blue (or greenish blue) when darkened, and toward violet when mixed with white. Green slightly bluish at the center when darkened becomes bluer, but decreasingly so as the amount of black is increased.

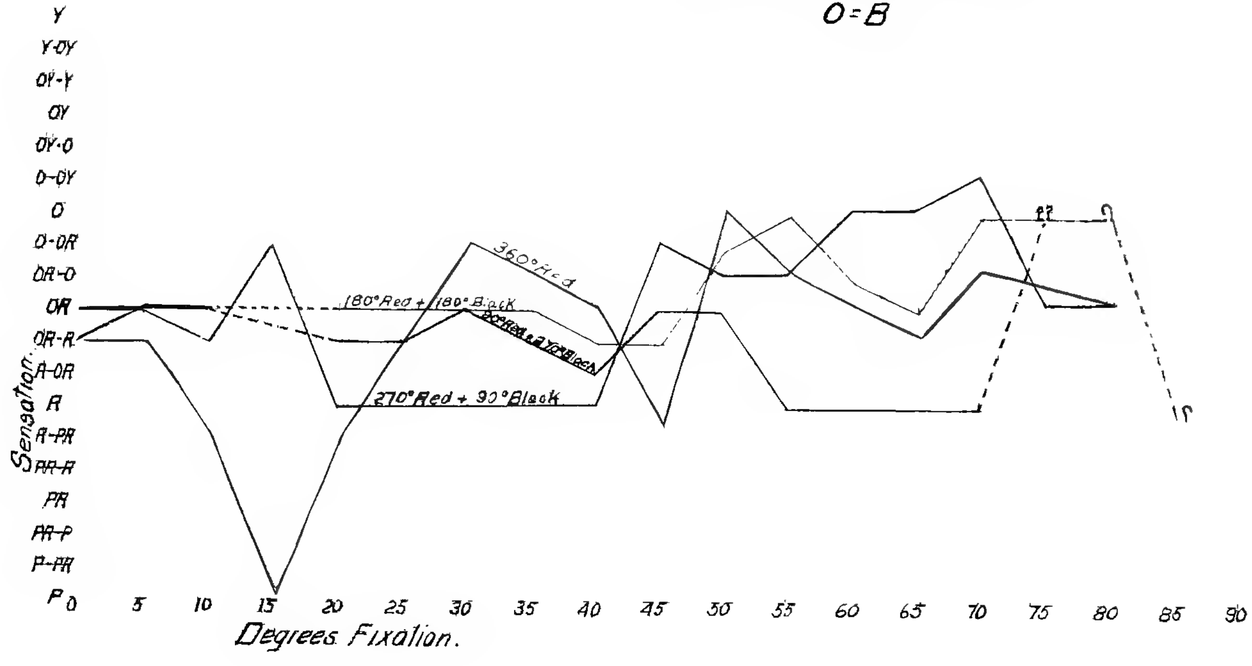
6. Changes in Hue during Fixation

In addition to the general shift of color tone from the center to the periphery, the observers reported frequently a shift in hue of a single color during fixation. There are marked individual differences in the number of changes reported, due partly to the fact that such changes were reported earlier in the work by some observers and were not specifically asked for by the experimenter until they had been spontaneously offered a number of times, and partly to individual differences as regards stability of the colors. Thus R, who seems to show great sensitivity to color,—when (with the grey background) the color was exposed as long as the sensation lasted, he often saw a color at the periphery for over a minute, and his after-images sometimes lasted even longer,—reported only two changes of hue during the entire period of observation. F reported the greatest number of changes; B was a close second. Tables X-XII give sample results from different observers for the three backgrounds.

With the grey ground, (1) the orange-red, orange, or orange-yellow sensations from red stimuli tend to shift toward red; (2) sensations from orange, orange-yellow, yellow, yellow-green and green (all seen as yellow or yellowish) shift toward yellow during fixation; (3) sensations from blue-green (seen usually as greenish blue or blue) shift toward green;

1.

STIMULUS = RED + BLACK
BACKGROUND = PLATINUM GREY
O = B

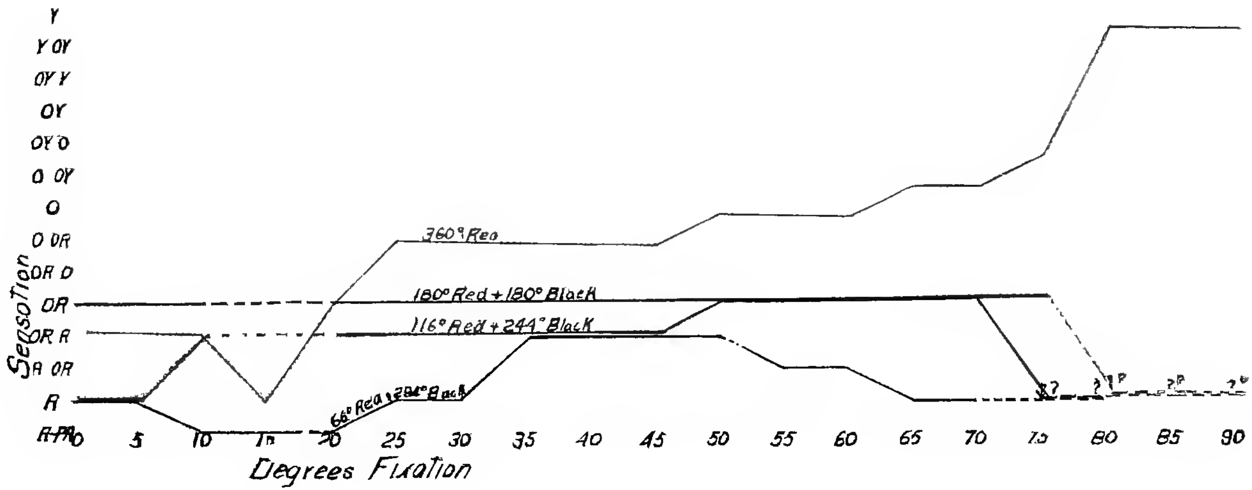


2

STIMNI US = RED + BLACK

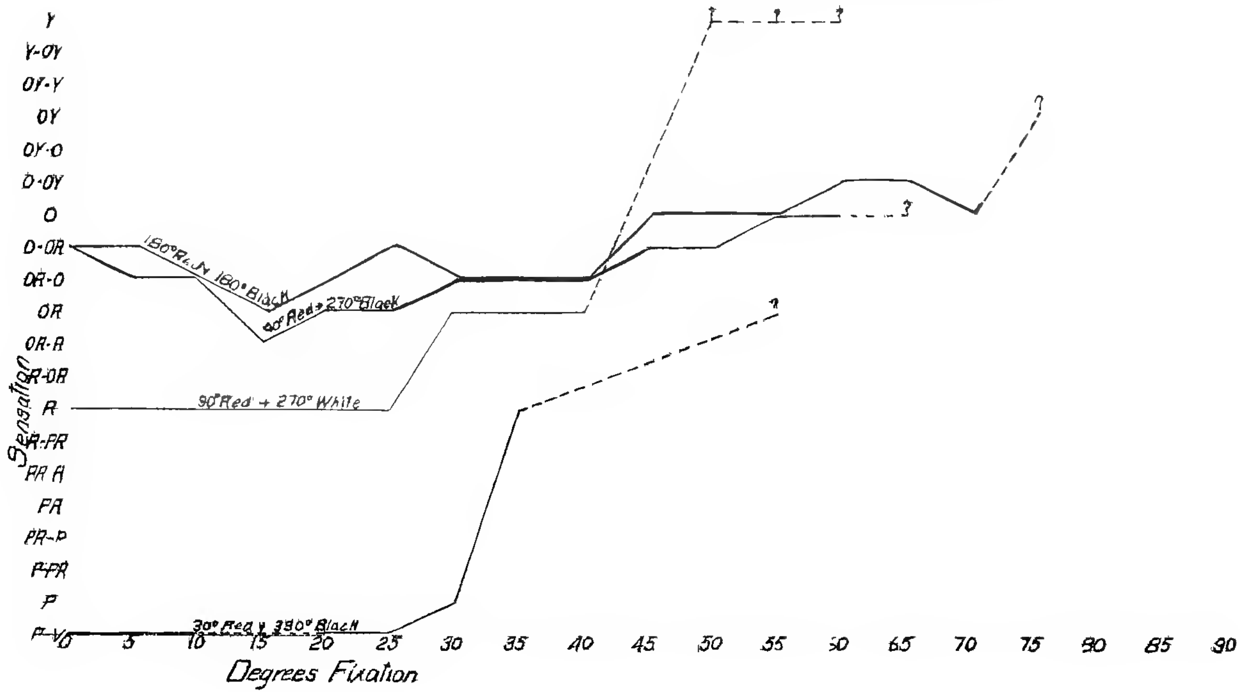
BACKGBOUND = PLATINUM GREY

O = D



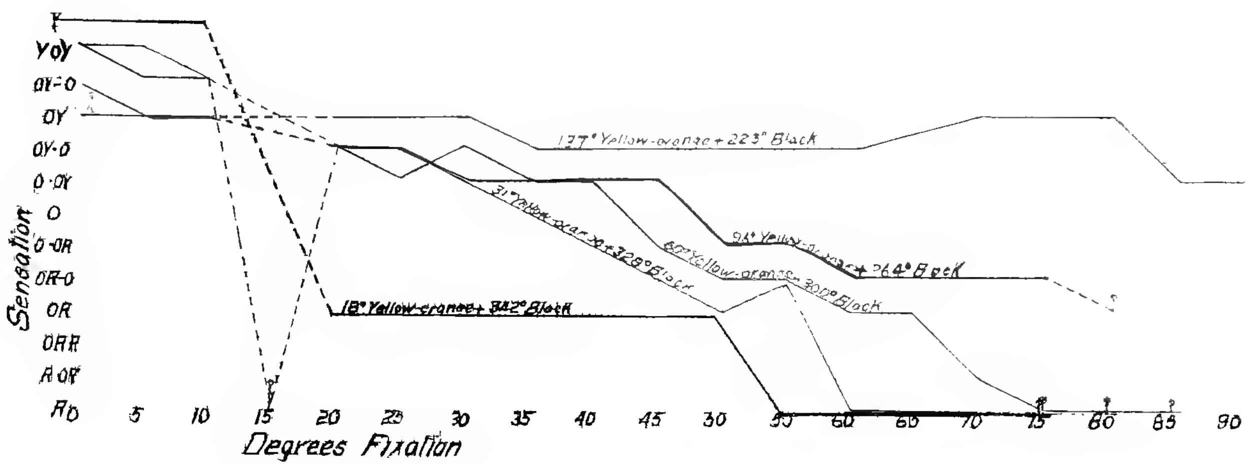
3

STIMULUS=RED+BLACK OR WHITE
BACKGROUND=PLATINUM GREY
O=G



4.

STIMULUS = YELLOW-ORANGE + BLACK
BACKGROUND = PLATINUM GREY.
O = D.



(4) sensations from blue, violet, and purple (seen usually as blue) shift slightly toward violet. The change is, therefore, toward the stimulus color with red, blue-green and violet and purple, and from it with orange, orange-yellow, yellow-green and green. In other words, sensations from red, yellow-green, green, and blue-green shift toward the red end of the spectrum, while sensations from orange, orange-yellow, yellow, blue, violet, and purple shift toward the violet end.

The case is somewhat different with the black background. Here (1) red, orange, orange-yellow, yellow, and yellow-green all change still further toward yellow; (2) green and blue-green are constant (no change was reported); (3) blue shifts toward blue-green; (4) violet and purple change toward blue. Thus, red, orange, orange-yellow, and yellow change in the direction of the violet end of the spectrum; yellow-green, blue, violet and purple shift toward the red end of the spectrum; green and blue-green are constant.

With the white background fewer changes were reported than with the other two. Here the change, when it occurred, was often too rapid for sure judgment of its direction; the colors seen were, moreover, so unsaturated that it was very difficult to pass judgment as to change in hue. In general, however, (1) red, orange, orange-yellow, yellow and yellow-green (all seen as reddish) become decidedly more red during fixation; (2) no change was reported in green; (3) blue-green, blue, violet, and purple all shift somewhat toward purple. Thus, red, orange, orange-yellow, yellow, and yellow-green shift toward red; green is constant; blue-green, blue, violet, and purple shift toward violet.

It was at first thought that these changes in hue might be due to poor fixation. If that were the case, we should expect to find the changes (1) always occurring in the direction of the stimulus, or (2) always occurring in the direction away from the stimulus, or (3) showing irregularity in direction. No one of these conditions, however, is found. Moreover, R gives evidence of occasional faulty fixation, but reports (except twice) no change in hue during the five seconds' fixation. We feel confident, therefore, that these changes represent a normal occurrence.

B. Changes in Tint and Chroma

At the center the colors are seen: (1) with the grey background, as generally medium in tint and good in chroma; (2) with the black background, as light in tint and very good in chroma; (3) with the white background, as dark in tint and

TABLE X

Grey Background

	Fix'n.	Stim.	Sensation	Change
O=B	85	OY	*OY*-O	vs. Y
	75	OY	OY	vs. Y
		Y	*Y*-OY	Y
	70	O	O-OY	Y
		OY	Y-OY	vs. Y
		P	*V*-P	V
	65	R	OR	vs. R
	60	OY	OY	vs. Y
	55	O	OY	Y
		YG	Y-GrY	vs. Y
	45	OY	O	Y
		YG	YG-Y	Y
O=F	85	OY	OY-Y	vs. Y
	80	OY	OY	Y
		YG	Y	vs. Y
		B	*B*-V	vs. V
	75	O	O-OY	Y
		G	GrY	Y
		R	*OR*-O	OY
	70	OY	*GrY*-YG	vs. Y
	65	O	OR	vs. Y
		OY	OR	Y-OY
		YG	GrY-YG	vs. G
		B	GrB	V-B
		O	O-OR	vs. Y
	60	O	OY	Y
	55	Y	OY	vs. Y
	50	O	OR	vs. Y
		Y	*O*-OY	Y
		Y	*Y*-OY	vs. Y
		P	P	vs. V
	45	R	*OR*-O	vs. Y
		OY	OY-OR	YG
		OY	OY-OR	vs. Y
		Y	GrY	Y
		Y	YG-GrY	vs. Y
		P	P	V-P
		V	B	*V*-B
		B	B	*V*-B
	40	R	O	OR
	30	R	O	OR
	25	BG	GrB	G-BlG

fairly good in chroma. With all three grounds, the colors become steadily darker and poorer as they approach the periphery. The change in tint is most rapid with the white ground, and least rapid with the black ground. With the latter ground, in fact, the colors become only slightly darker, fading out to

TABLE XI

Black Background

	Fix'n.	Stim.	Sensation	Change
O=B	75	O	O-OR	vs.O
		R	*O*-OY	vs.Y
	65	Y	OY-Y	Y
	55	O	O	Y
	50	O	O	vs.Y
O=F	90	Y	*OR*-O	*OY*-O
	80	R	*O*-OY	vs.Y
	70	P	P	B
	60	Y	OY	vs.Y
	55	R	OR-R	vs.O
		OY	*O*-OY	vs.Y
	50	O	*OR*-O	Y
	25	O	OR-O	vs.Y
		Y	*YG*-GrY	vs.Y
O=T	90	B	P	B
	80	R	OY	vs.Y
	75	V	P	B
	65	V	P	B
	45	R	O+OR	vs.O
	30	YG	*YG*-YeG	Y
	25	Y	GrY	Y

TABLE XII

White Background

	Fix'n.	Stim.	Sensation	Change
O=B	85	OY	O	OY-Y
	75	P	OR	O
	70	O	OR-O	OR
		OY	O	OR
		YG	OY-O	*O*-OY
		B	B	P
	65	BG	B	P
	60	R	O	*OR*-O
		YG	*OY*-O	*OY*-Y
		P	B	*V*-P
	55	R	O-OR	vs.R
	45	P	P	vs.B
	40	R	*PR*-P	B
	30	V	B	vs.V
	25	OY	O-OY	Y
	20	O	OR	vs.R
O=G	45	R	OR	R
	40	O	O	*O*-OR
		Y	*Y*-OY	Y
		P	B	*P*-V

light grey, while with the white ground they become darker at a rapid pace and pass over into black. The results with the grey ground are, as usual, intermediate; the colors fade into darker greys.

C. Variations in Duration of Sensation

As a rule, the stimuli were exposed for uniform periods of 5 seconds. It was incidentally noted, however, when longer exposures were given, that the duration of the sensations as colored was definitely correlated with the angle of fixation and with the brightness of the background. The black ground is perhaps the most, and the white ground the least favorable to persistence of sensations. With all three grounds adaptation becomes rapid as the periphery is approached. On the more extreme peripheral points the sensations show a tendency toward a flash-like appearance. This tendency is least marked with the black ground, occurring only twice (with D, for green and purple stimuli). With the grey ground, 15 occurrences of "flash" sensations were noted, at fixation points from 70 to 90 degrees, with purple (9 times), red, green, blue-green, and violet. The white ground gives the greatest number, 52 occurrences. Of these, four occur at 90 degrees, four at 85 degrees, thirteen at 75 degrees, eleven at 70 degrees, one at 65 degrees, two at 60 degrees, three at 55 degrees, and one at 50 degrees, with all stimuli, though most often with purple (9 times), blue-green (8 times), and yellow-green (7 times).

II. Effect of Background on After-Image

A. Change in Hue

1. With Medium Grey Background

With the medium grey background, the after-images of: (1) red stimuli change from bluish green at the center to greenish blue or blue, except for R, whose after-images are practically constant (blue-green); (2) orange stimuli change from blue-green (or greenish blue) to greenish blue, and finally, for B and F, to blue; (3) orange-yellow stimuli change from greenish blue to blue; with F and R they even show a tendency to shift toward violet; (4) yellow stimuli are fairly constant (blue), but shift occasionally toward violet for B, F, and R; (5) yellow-green stimuli are violet or purple at the center, but change to blue (they are occasionally greenish-blue at the periphery); (6) green stimuli are constantly purple for B, but shift to violet for F and R, and to blue for D (and

once for F); (7) blue-green stimuli change for B from orange-red to orange-yellow, and for D and R to orange; (8) blue stimuli change from orange-yellow to yellow for B and F, are fairly constant for D, and change to orange for R; (9) violet stimuli change from yellow-green or greenish yellow to yellow for all observers; (10) purple stimuli change from green to yellow for B and R, to orange-yellow for D, and to greenish yellow for F. (See table XIII for typical set of

TABLE XIII

O=F Grey Background

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
90	—$_4$ B-GrB	—$_3$	—	—	B GrB-BG	—	Y	Y GrY-YG_2 OY-Y GrY	—	—
85	—	B_2	V-B	B B-V	B-GrB	— B	Y	Y	Y	GrY?
80	GrB	GrB	B-GrB	*B*-V	*B*-GrB	—	OR-O	Y	OY	—
75	BG	GrB	*V*-B	B	B	—	OY_2	Y	Y	Y
70	GrB	GrB_2	B-V	GrB B	B	—	Y	Y	Y	GrY
65	*GrB*-BG_2	GrB	V-B	*B*-V?	V	—	OY	Y-OR	*Y*-GrY	YeG-YG
60	GrB-BG	GrB	*V*-B	V-B	B-V	*V*-B	OY	OY	*GrY*-YG	YG-YeG
55	BG	GrB	*B*-V	*B*-GrB	—	V	*O*-OY	Y	YG-GrY	YG-YeG
50	GrB-BG	GrB	*GrB*-B	B-V B?	BG *V*-P	*V*-B	*O*-OR_2	YG-GrY	*YeG*-YG	YeG YeG-YG
45	GrB BG	GrB	V *V*-B	V_2	V	V-P	OR-O	Y	YG-YeG	YG? *YG*-GrY *YeG*-G
40	GrB	GrB	V	*V*-B	V	*P*-PR	*OR*-O	OY	YG-YeG	YG-YeG
35	GrB	GrB	V-B	B	V-P	P	*O*-OR	OY-Y	YG	YeG
30	GrB-BG	GrB	GrB-B	B	*V*-P	P	*O*-OR	O-OR	YG	G-YeG
25	BlG	GrB-BG	GrB	B	*P*-V	P-PR	O-OR	Y-OY	*YG*-YeG	*G*-YeG
20	BG-BlG	GrB-BG	GrB	B	*P*-V	P-PR	O-OR	OY-Y	YG	G

results.) It is evident that there is a good deal of variability in the results; we can, however, indicate certain general tendencies. After-images whose components are blue and green change slightly toward the violet end of the spectrum; green after-images and those whose components are red and yellow shift toward yellow; purple after-images shift toward blue. If, now, we disregard the stimuli and consider the after-images merely with reference to the sensation qualities, we find that after-images of the different sensation qualities are always those that we get with the same sensations in central vision. They all, therefore, change in correspondence with

TABLE XIV

O=D Black Background

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
90	—	—	—	B	BlG?	—	—	—	—	—
85	BlG?	—	BlG?	BlG	—	—	—	—?	—	—
80	— GrB-BG	—[2]	BlG BG-GrB	GrB? —	— G?	—[2]	—[2]	OR-O? R??	—[2]	—[2]
75	—	GrB-BG?	BG-GrB	GrB	—	—	—	OR-O	OR	—
70	BG-GrB	BG-GrB	BG-GrB	B	—	—	—	—	OR?	—
65	BG	BG-GrB	GrB-BG	GrB-BG B	B	—	—	OR-O	OR-O	—
60	BG	BG	BG-GrB	B	B	B	OR-O	O-OR	OR-O	—
55	BG-GrB	GrB	B	B	B P-PR	B	OR-O	OR-O	O-OR	—
50	GrB-BG	BG	GrB-BG	B	B	OR??	OR-O	OR-O	OY-GrY	O-OR
45	B	—	B	B	B	P	OR	O-OR	OY-O+YG	—
40	BlG	BlG	GrB	V	P	P	OR-R	OR+YG	O-G	YG-YeG
35	BlG-G	BlG-G	B	B	P	P	O	OY-O	YG	YG-YeG
30	BlG	BlG	B	B	P-PR	P-PR	O-OR	O-OY	YG	YG-YeG
25	BlG	BlG-BG	B	B	P	P-PR	O-OR	OY-O	YG	YG-YeG
20	BG-BlG BlG	BG-BlG	B-V GrB	B-V B	—	P-PR	*OR*-O OR-O	OY O	YG	YG-YeG

changes in their sensations, so that they are always the complementary hues to those sensations in central vision.

2. With Black Background and Projection Ground

(See table XIV for representative set of results.) Here we find that the after-images of: (1) red stimuli shift from bluish green to greenish blue, for D, and usually to blue for the other observers; (2) orange stimuli follow a similar course from blue-green to greenish blue with D, F, and Ge, and to blue with B, R, and T; (3) orange-yellow stimuli show great variability, becoming greenish with D, and remaining bluish (occasionally violet) with the others; (4) yellow stimuli show many slight fluctuating changes, so that it is impossible to say more than that they are fairly constant (blue) for all except D, for whom they incline toward green; (5) yellow-green stimuli are constant (purple) for T, and shift to blue or greenish blue for the others; (6) green stimuli shift from purple to violet for R, and to blue for the others; (7) blue-green stimuli shift from orange-red to orange for B, to orange-yellow for Ge, R and T, but are fairly constant for D and F; (8) blue stimuli shift from orange-yellow or yellow to orange-red for B, D, and T, and to orange for F, but are fairly constant for Ge and R; (9) violet stimuli shift from yellow-green or greenish yellow, to orange-red for B, D, and T, to orange-yellow for R, and to yellow for F and Ge; (10) purple stimuli change from green (slightly yellowish) to a hue between orange and orange-red for D and F; to greenish yellow for T; to yellow-green for Ge and R; and are constant for B (for all except D and F they are soon colorless). The general trend is, then, that after-images whose components are blue and green shift toward blue; purple shifts toward blue; orange-red may or may not shift toward yellow; all other after-images whose components are red and yellow or green and yellow shift toward red. If, now, we consider the after-images in relation to their sensations, we find that after-images of: (1) red sensations tend to shift from green or bluish green to greenish blue (or even blue); (2) orange sensations change from blue-green toward and even to blue; (3) orange-yellow sensations tend toward blue from greenish blue; (4) yellow sensations are usually blue or greenish blue; (5) yellow-green sensations are practically always of a hue slightly to the violet side of purple; (6) green sensations change from a reddish purple to a hue between purple and violet; (7) blue-green sensations change from orange-red more or less in the direction of yellow; (8) blue sensations remain constantly yellow

or change in the direction of red; (9) violet sensations change from yellow-green in the direction of red (once even to orange-red); (10) purple sensations tend to shift from green to yellow-green, to orange, or even to orange-red. Thus, after-images are fairly constant only for yellow-green and, possibly, blue and yellow sensations, and sometimes for blue-green stimuli.

3. With White Background and Projection Ground

Table XV gives a sample of the results for one observer. With the white background and projection ground, the after-images of: (1) red stimuli change from bluish green, at the center, to greenish blue for D and F, to blue for G, and to violet for B and R; (2) orange stimuli change from blue-green or greenish blue toward blue, becoming greenish blue for D and R, blue for F and G, and violet for B; (3) orange-yellow stimuli are constantly greenish blue for F, change to blue for D, G, and R (?), and to purple for B; (4) yellow stimuli are constantly blue for D and G, but change to violet for B, F, and R (?); (5) yellow-green stimuli change from purple or reddish purple to greenish blue for D, to blue for G, and to violet or blue for B, F, and R; (6) green stimuli change from red or purplish red to purple or violet (R); (7) blue-green stimuli change from purplish red to yellow for D and G, from purple to yellow-green for R, and from a reddish orange to yellow or yellow-green for B and F; (8) blue stimuli change for B from orange-yellow to yellow, for D and G they are constantly yellow, for F and R they become greenish yellow; (9) violet stimuli change from greenish yellow to yellow for all except F, for whom they change from yellow-green to greenish yellow; (10) purple stimuli change from yellowish green to yellow for all except F, for whom they are always somewhat greenish. The general trend is, then, that after-images whose components are blue and green become bluer (even violet); those whose components are red and yellow shift toward green, and those whose components are green and yellow change more or less toward yellow. If, now, we consider the after-images in relation to the sensation qualities, we find that after-images of: (1) red sensations change from bluish green to blue or even to violet; (2) orange sensations change from blue-green to blue or violet; (3) orange-yellow sensations change from greenish blue to blue or violet; (4) yellow sensations change from blue (or violet) toward violet (or purple); (5) yellow-green sensations are fairly constantly purple; (6) green sensations change from red

TABLE XV

O=R White Background

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
90	$—_4$	$—_3$	$—_3$	$—_3$	$—_3$	$—_3$	YG —	$—_3$	$—_4$	$—_4$
85	$—_2$ V	$—_3$	$—_3$	$—_3$ B GrB_2 V_3	$—_4$	$—_4$ Y	$—_3$ Y	$—_2$ Y GrY-OY OY	Y_3	— Y
80	$—_4$ BG V	$—_3$ BG	— BG	— GrY	$—_3$ V_2 B	— Y	$—_2$ —	— Y_2	$—_2$ GrY_2 Y_4 GrY_3	— YG Y
75	BG	GrB	B GrB	V	V_{10} B GrB P_2	V —	GrY	Y	Y_{10} $—_2$	—
70	—	BG	B	BG	B —	—	—	Y	Y_2 $—_3$ GrY	$—_2$
65	V	V	GrB	BlG	—	V	Y	Y	GrY	Y_2
60	GrB	BG	BG	GrB	GrB	—	Y	Y	GrY	—
55	V BG	GrB	GrB	GrB	V	V	Y	OY-Y	GrY_3	—
50	BlG	BG	BG	GrB	V	V	Y	Y	Y	—
45	BlG	BG	GrB	B	V	V	O_2	Y	YG	YeG
40	BlG	BG	BG	B	V-P	P	R	Y	Y	YG
35	G	BG	BG	GrB	P	P	R	Y	GrY	YeG
30	BlG	BG	BG	V	V-P	V	OR	Y	YG	YG
25	G	YeG	GrB	V	P	V	P	Y_2	GrY	YeG
20	BG	BG	GrB	P	P	P	P	Y	GrY	YeG
5	—	BG	GrB	V	V	—	P	Y	—	GrY
0	BG	BG	BG	V	V	PR	—	Y	Y	YeG

or purplish red toward purple; (7) blue-green sensations change from purple-red or orange-red toward yellow-green; (8) blue sensations are constantly yellow (or become greenish yellow); (9) violet sensations are yellow-green or greenish yellow at the center and shift toward yellow; and (10) purple sensations shift from yellowish green or green to yellow-green or greenish yellow or even to yellow. Thus, the after-images are never constant for their stimuli, and are fairly constant only for yellow-green (purple) and possibly for blue (yellow) sensations.

4. With Black Background and Grey Projection Ground

Table XVI gives the results with the black background and grey projection ground for the same observer (D) whose results with the black background and projection ground are given in Table XIV. It may be sufficient to note that the results are quite different for the two projection grounds, especially for blue-green, blue, violet, and purple stimuli. There is, however, very close agreement with the results for the grey background and projection ground.

TABLE XVI

O=D

Black Background
Grey Projection Ground

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
90	GrB	GrB?	B?	B	GrB?	—	Y?	OY Y	OY	—
85	GrB	GrB	B GrB-BG	GrB?	GrB	—	Y-OY	OY	O-OY	Y-OY
80	GrB	GrB	GrB	GrB	BG	—	OY-O	Y	OY	Y
75	GrB	GrB	GrB	GrB	GrB-BG GrB	—	OY	OY-O OY	OY	Y
70	GrB	OY	GrB	B GrB-B	GrB_2	—	OY-O	Y-OY OY	Y	Y?
65	GrB-BG	B-GrB GrB-BG V-P	GrB_2	GrB	GrB-BG	—	Y Y?	Y-OY OY-O	GrY	—
60	BG-GrB	GrB	B GrB	B GrB	B	—	OY+GrY	Y-OY	Y	Y

5. With White Background and Black Projection Ground (See Tables XVII and XV for sample results with this

TABLE XVII

O=R

White Background
Black Projection Ground

Fix'n. °	Stimuli									
	R	O	OY	Y	YG	G	BG	B	V	P
85	—	—	—	—	—	—	—	—	—	—
80	—	—	—	GrB B	—	—	—	—	—	—
75	BlG	B	GrB	B	—	—	—	—	—	—
70	GrB	B	B	B_3	—	—	—	O	—	—
65	GrB	B	GrB	B	GrB	—	—	O	—	—

method, and with the white background and projection ground.) As in 4, the results seem primarily dependent on the brightness of the projection ground. Here, the blackness of the projection ground is, evidently, enhanced by contrast with the white background; quite consistently, we find the results in this case showing an exaggeration of those with the black background and projection ground.

6. Comparison of Results for 1-5

A comparison of the results for the various combinations of background and projection ground brings out, first, the very evident fact that it is the difference in brightness of the projection ground that is responsible for the difference in the courses of the after-images. It is plain also that the after-image hues show the same dependence on brighteness that the same hues do when experienced as sensations. If, however, we try to find a definite correlation between stimulus or sensation (or both) and after-image for all backgrounds, we find an apparent lack of uniformity. In the case of the grey ground alone is there anything like consistency. Here we see that the hue of any after-image may be incidentally the complement of its stimulus, but is *always* the complement of its sensation. The medium grey thus seems to present a standard set of conditions with which to compare those of the black and white grounds. Dealing first with the black ground,

as compared with the grey, we note that the most peripheral after-images of: (1) red stimuli (bluish green at the fovea) are slightly greener; (2) orange stimuli (blue-green) are practically the same (slightly greener); (3) orange-yellow stimuli (blue) are as a rule greener; (4) yellow stimuli (blue) are practically the same (possibly greener); (5) yellow-green stimuli (violet or purple) are practically the same; (6) green stimuli (purple) are practically the same (possibly bluer); (7) blue-green stimuli (orange-red) are redder; (8) blue stimuli (orange-yellow or yellow) are redder; (9) violet stimuli (yellow-green or greenish yellow) are redder; (10) purple stimuli (yellowish green) are redder. We find, on the other hand, if we compare the results for the white ground with those for the grey, that, for the former, the most peripheral after-images of: (1) red stimuli (bluish green) are redder; (2) orange stimuli (blue-green) are slightly redder; (3) orange-yellow stimuli (between greenish blue and blue-green) are practically the same (usually redder); (4) yellow stimuli (blue) are perhaps redder; (5) yellow-green stimuli (purple) are redder; (6) green stimuli (purple) are redder; (7) blue-green stimuli (orange-red) are distinctly greener; (8) blue stimuli (orange-yellow or yellow) are distinctly greener; (9) violet stimuli (yellow-green or greenish-yellow) are greener; (10) purple stimuli (yellowish green) are perhaps greener. The results from the black and white grounds are thus seen to show opposite trends with reference to the grey background. They seem, moreover, to correspond closely with the results that ensued in the case of the sensations, where: (1) darkening of the stimuli made red, orange, orange-yellow, yellow, yellow-green, and yellowish green all shift toward red, and made bluish green, blue-green, blue, violet, and purple all shift toward green; while (2) lightening of the stimulus made red, orange, orange-yellow, yellow, yellow-green, and yellowish green all shift toward green, and bluish green, blue-green, greenish blue, blue, violet, and purple shift toward purple. In other words, darkening sensations or after-images makes them shift toward the red end of the spectrum, lightening causes a shift toward the violet end. Taken as a whole, the results suggest that (1) we have in every case, no matter what the brightness of the background may be, the same processes in the retina for a given stimulus at a given fixation (namely, the processes resulting with use of the medium grey background); that (2), however, the simultaneous occurrence of the black or white process results in a tendency for the colors experienced to shift in a definite spectral direction.

It is hardly possible to compare our results with those obtained by Fernald, since these are given in too little detail. We must assume, from such statement as she makes, that her concern with them was comparatively slight; and we think that her method was evidently not calculated to bring out fine details.

7. Effect of Changing Brightness of Projection Ground for the Same After-Image

(See Table XVIII for results.) This method was not always successful, in that sometimes the double movement across the field was distracting, and therefore only one after-image was noted. When, however, the two colored after-images were obtained, they showed changes in hue which were characteristic for their projection grounds. Thus, when the change is from a light to a dark background, the after-images whose components are blue and green shift toward green, those whose components are red and yellow shift toward red, as also do those whose components are yellow and green. A consistent change in the opposite direction occurs when the change of background is from dark to light. These results are also consistent with the view that the same retinal processes for color occur even when the resulting sensations or after-images are different.

8. Changes During Fixation

As in the case of the sensations, so the observers showed a tendency to report changes in the hue of the after-images during fixation. Sometimes the after-images which fluctuated recurred as different in hue; often, also, persistent after-images underwent a gradual change in color tone. Tables XIX-XXI give typical results. Here, as with the sensations, the changes are fairly consistent for given projection grounds. With the white background they occur only with the red, orange, orange-yellow, yellow, and yellow-green stimuli; the shift is always toward the red end of the spectrum. There is less uniformity in the cases of the grey and black backgrounds; though this result may be due to the poorer saturation of these after-images, and to the correspondingly greater difficulty of judging changes in hue. In general, however, with the black background, the after-images of red, orange, orange-yellow, yellow and (usually) yellow-green stimuli shift toward the violet end of the spectrum; and those for green, blue-green, blue, violet, and purple stimuli change toward the red end of the spectrum. With the grey background, after-images of red, orange, orange-yellow, yellow, and yellow-green

stimuli shift toward the red end of the spectrum; and those for green, blue-green, blue, and violet shift toward the violet end. Thus, with the white background, after-images on the green-blue-violet half of the spectrum shift gradually toward the

TABLE XVIII

Grey Background

O	Fix'n.	Stim.	Sensation	After-images		
				Grey P. G.	Black P. G.	White P. G.
D	85	Y	OY	GrB-BG	(1)BlG	
		P	B?	(1)Y	OY	
	80	R	*O*-OY	(1)GrB-BG	BG??	
		OY	Y	GrB	(1)BlG	
G		B	B	*OY*-Y		(1)Y?
D	75	O	*OY*-O	(1)GrB	BG-GrB	
	70	OY	*OY*-Y	(1)B	BG?	
		YG	Y	GrB	(1)GrB-BG	
R		B	B		OR	(1)Y
B	65	O	OY-O	PR?	(1)V?	
D		V	B	(1)*GrY*-YG	OR	
		V	B	*GrY*-YG	*R*-OR	
		V	B	Y-GrY?	(1)OR	
		V	B		OR	(1)GrY
		V	B		(1)OR-O	Y?
		BG	GrB-BG	(1)GrY	R-OR	
		BG	GrB-BG	YG?	(1)OR	
	60	BG	GrB-BG		OR	(1)Y
F		YG	OY; GrY-YG		GrB-BG	(1)*P*-V
B	55	B	B	*O*(-OR)	(1)*OR*-O	
D		YG	Y	BG		(1)B(-V)
	50	O	OY-O	GrB	(1)BG	
B	45	B	GrB	OY	*OR*(-O)	
		B	B	Y-OY		(1)GrY
		B	GrB		O	(1)Y
		B	B		(1)O	Y
D		P	P	(1)YG-GrY	OR-O	
	40	YG	YG-GrY	(1)P-V	B	
		YG	Y-GrY	*P*-V	(1)B	
		YG	GrY-Y	(1)P-V	GrB-BG?	
G		B	B	Y	(1)*O*-OR	
		B	B	(1)Y	OR	
		B	B		OR	(1)Y
		B	B	O		(1)Y
		V	B	(1)Y	OR	
		P	*P*-PR		Y-GrY	(1)Y
	30	P	P	(1)YG		Y?
		P	P	YG	(1)G	
B	25	G	G-BlG	PR	(1)*P*-PR	
F		YG	YG	PR-P?	(1)*V*-P	
D	20	O	OY-O	BG	(1)BG-BlG	

red end of the spectrum; the others are presumably constant. With the grey background, after-images on the green-blue-violet end of the spectrum shift similarly, though less markedly, toward the red end; those on the red-yellow-green half shift toward the violet end. With the black background, after-images on the green-blue-violet half of the spectrum change toward the violet end; those on the red-yellow-green half shift toward the red end. Inasmuch as the chroma of the after-images always becomes poorer, it is conceivable that the difference in results for the white and black grounds as compared with the grey is due to the difference in direction and amount of the change in brightness (which is, of course, toward middle grey).

B. Changes in Tint and Chroma

The tint of the projection ground has a marked effect on the tint of the after-image. All observers show the same general trend. The after-images are lightest with the white background and darkest with the black. With the grey ground they are about medium in tint at the center (those for green, blue-green, blue, violet and purple are rather lighter), and become slightly lighter; with the white ground they are light, and grow steadily lighter; with the black ground they are dark (with the same variations as with the grey), becoming darker toward the periphery.

As regards chroma, the results hardly warrant more than the

TABLE XIX

Grey Background

	Fix'n.	Stim.	Sensation	A. I.	Change
O=D	85	OY	OY-O	B	GrB-BG
	80	OY	*Y*-OY	B-GrB	vs.G
	70	OY	*OY*-Y	B	GrB
		O	OY...O	B-GrB	BG-GrB
		YG	OY-Y	GrB	BG
	65	YG	Y	B	GrB
		OY	*OY*-Y	B	B-GrB
	60	OY	OY-O	B	GrB
		Y	Y	B	GrB
O=R	70	B	GrB	OY	O
	65	O	*O*-OR	B	*P*-V
	60	YG	Y	BG	V
	55	BG	B	O	OY
		G	Y	B	V
		Y	Y	B	BG
		OY	O	B	GrB

statement that the black ground is least favorable to peripheral after-images. The white ground appears to be most favorable to peripheral after-images, especially to those from blue stimuli. The observers show decided individual differences with regard to chroma; thus R's after-images are comparatively good, while F's are always poor.

TABLE XX

Black Background

	Fix'n.	Stim.	Sensation	A. I.	Change
O=B	50	YG	Y	B	P
	35	Y	Y	P-PR	V
		YG	Y	P	B
	30	R	R	G	B?
		O	*O*-OR	BlG	BG-GrB
		Y	Y	B	*V*-B
		YG	Y-OY	P	V
	25	O	O-OR	G	BG
	20	YG	YG	P	V-P
O=D	55	YG	Y	B	P-PR
	50	V	V-GrB...P	OY	GrY
	45	V	B-V	OY-O	YG
	40	P	P	YG-YeG	BlG
		O	O-OY	BlG	YeG
		OY	OY	GrB	YeG
	35	BG	BG	O	OR
		R	O-OY	BlG-G	GrB-BG
		YG	YG-GrY	P	V
	30	OY	OY	B	BG
		G	YeG	P-PR	B?
	25	B	GrB...BG	O	OR
		G	GrY-YG?	P	B?
	20	B	GrB...BG	OY	OR
		P	*P*-PR	YG-YeG	YG

TABLE XXI

White Background

	Fix'n.	Stim.	Sensation	A. I.	Change
O=D	80	Y	OY	B	GrB
	75	Y	Y-OY	B	GrB-BG
	65	YG	*OY*-Y	GrB	BG
		OY	O; OR	GrB	BG
	55	Y	OY	GrB	BG
		R	OR	B-GrB	GrB-BG
		YG	*Y*-OY	B	*GrB*-BG
		OY	*OY*-O	B	GrB

C. Frequency of After-Images

The observers show considerable variation in respect to the frequency with which colored after-images follow colored sensations. With R the occurrence is practically universal; with the black background, however, about five *per cent.* of his color sensations fail to be followed by colored after-images. The other observers show a slightly greater number of such failures. Inasmuch as the work with the black background was done almost entirely in the summer, under the best possible conditions of illumination, it seems evident that for our observers, at least, the black background is less favorable than the others to colored after-images. The grey background supplies the most favorable conditions, *i, e.,* gives the largest *per cent.* of colored after-images.

Inasmuch as our results (though they agree with those of Fernald) are, in this respect, at variance with those of Ferree and Rand, we give here the further support to our view obtained by the additional tests. We adopted a fixation-time of 2 (sometimes 3) seconds, and, keeping the procedure otherwise as before, required the observers to fixate the black ground either 5 or 10 seconds before exposure of the stimulus. The result showed some reduction in the saturation of the sensations, but always a correspondingly greater reduction in the after-images. We then, in addition, omitted all preparatory signals (on the assumption that this might possibly have been the Bryn Mawr procedure); the after-images suffered, however, as much as, if not more than, the sensations. In every case, the observers reported that the sensation was unquestionably and decidedly more saturated than the after-image. We then reduced the chroma of the stimulus by gradual addition of white, until the color passed below the limen. As before, the after-image was affected even more than the sensation, until the stimuli were so reduced that it became merely a matter of guessing for both sensation and after-image. We are forced, therefore, to hold to the belief that the black background is the least favorable for after-images.

D. Types of After-Images

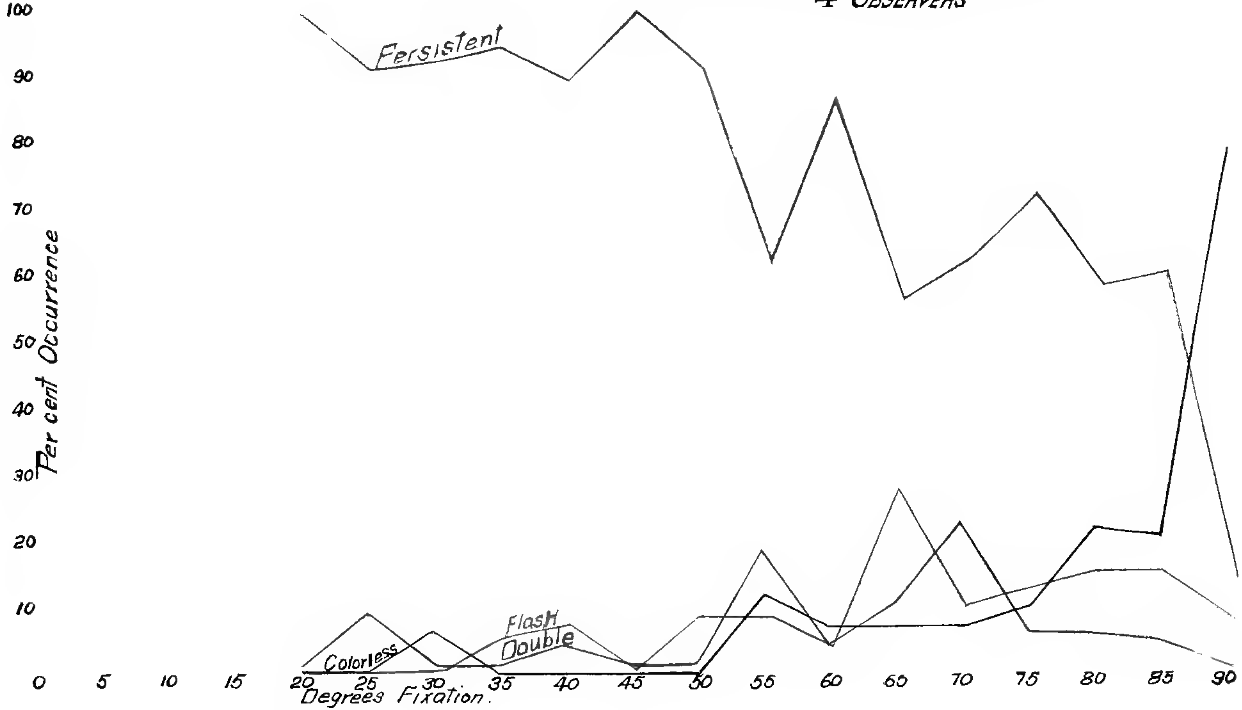
As with the sensations, the brightness of the background has a distinct influence on the duration of the after-images. It has been shown that there are two types of color sensation, designated as the "flash" and the "persistent" sensation, and that the "flash" type tends to occur at the more peripheral points, and most frequently with the white background, the

ground least favorable to color-sensations. In the case of the colored after-images we also find the two types, the flash-like and the persistent; and, in addition, a third type of occurrence which will be called that of " double " after-images. The double after-images are a succession of the flash and persistent types, occurring with a single stimulus. Figures 5-7 give a graphic representation of all types of after-images occurring with colored stimuli for each background (flash, persistent, double, and colorless). The values given are the estimated mean *per cents.* of occurrence for all observers. It will be seen that: (1) the flash-like after-images occur most frequently at fixation points of from 55-65 degrees; they are reported most often with the black background and least often with the white; (2) the persistent after-images occur most frequently with the grey background, slightly less often with the white ground, and least frequently with the black; they are most frequent at the fovea and least at the periphery; (3) the double after-images occur rarely except with the black background; here they attain an early maximum and then rapidly decrease; (4) the black ground gives the largest number of colorless after-images until a fixation of 65 degrees is reached; from that point on, the increasing number of colorless sensations with the white ground causes a coresponding increase in the number of colorless after-images reported. There is marked individual variation in the frequency of occurrence for the different types. D has the largest number of flash after-images; R, all of whose color sensations are persistent, reported no flash after-images. R and F reported almost no double images.

Flash after-images were experienced with all stimuli, but most often with those that were seen colored farthest out. The fact that they were experienced in a uniform way, most frequently, both as sensations and as after-images, with the least favorable backgrounds, seems to suggest that they are not the result of eye movement, as might at first be assumed. It seems more likely that they are in some way dependent on the movement of the projection screen across the field of the stimulus. They occur, subjectively, simultaneously with the perception of this movement. They occur, moreover, under conditions which are unfavorable to color experiences, that is, most often with the least favorable backgrounds and fixation points. They are experienced most often for the part of the visual field that is most sensitive to movement. It is, therefore, conceivable that the rapid but not instantaneous movement of the screen heightens in some way the otherwise subliminal value of the stimuli.

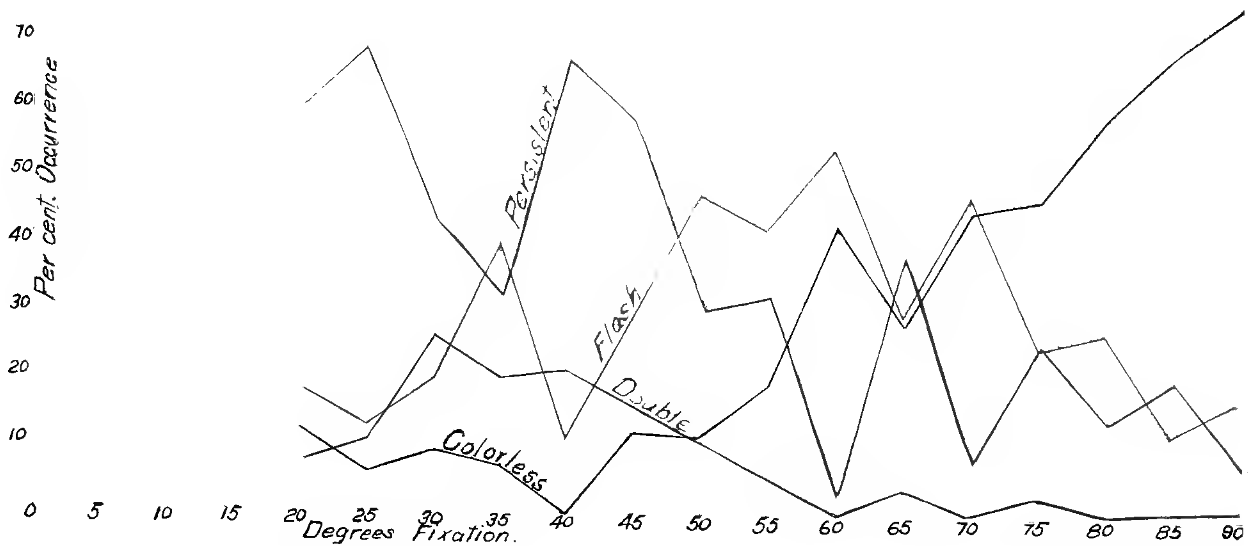
5

DISTRIBUTION OF TYPES OF AFTER IMAGES
BACKGROUND = PLATINUM GREY
4 OBSERVERS



6.

DISTRIBUTION OF TYPES OF AFTER-IMAGES
BACKGROUND = HERING BLACK
6 OBSERVERS

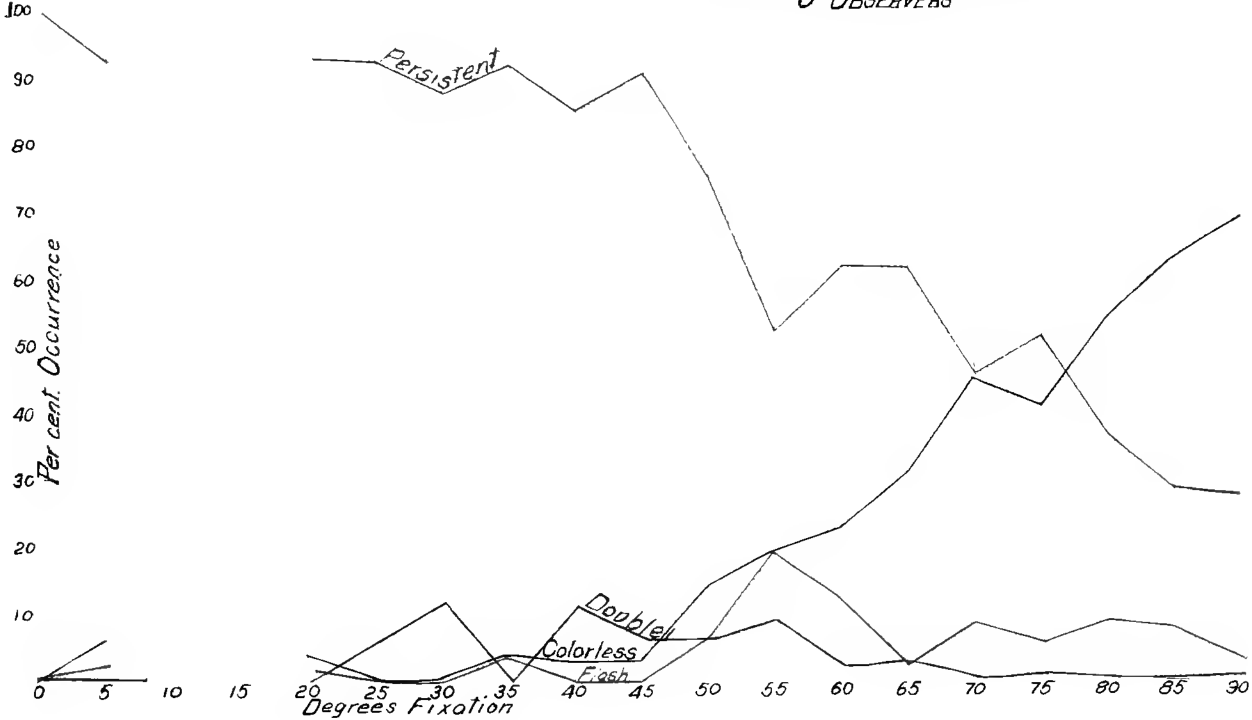


7.

DISTRIBUTION OF TYPES OF AFTER-IMAGES

BACKGROUND = PLATINUM WHITE

5 OBSERVERS



III. Anomalous Results

A. General Classification

Along with the consistent and uniform results, there were reported a number of apparently anomalous occurrences. In this class we have included, perhaps too arbitrarily, such types of occurrence as: (1) colored sensations from colorless stimuli; (2) colored after-images from colorless stimuli; (3) colored after-images from colorless sensations; (4) other cases of anomalous hues reported with colored stimuli; and (5) all instances of colors seen during the fore-period of a given observation.

We will consider first those cases in which the anomalies occurred with colorless stimuli. These were reported with all backgrounds, on both bright and cloudy days, for all observers except Ge. With the grey ground 22%, with the black 6%, and with the white 9% of the total number of colorless stimuli gave colored sensations and after-images (these might or might not be complementary). The *per cents.* are 3, 15 and 12 respectively (for the three backgrounds), for reports of colored sensations and colorless after-images; and 3, 9, and 10 respectively, for reports of colorless sensations and colored after-images from these stimuli. We find, then, adding the *per cents.* for the three varieties, 28% anomalies with the grey ground, 30% with the black ground, and 31% with the white ground. There are, furthermore, a number of reports of color seen while the observer was resuming his fixation, or waiting for the stimulus to be exposed.

Greater in actual numbers, but smaller in *per cent.* of frequency, are the apparent anomalies with colored stimuli. These, also, occurred with all three backgrounds, with both good and poor illumination, and with all observers except Ge. Least conspicuous (because it is here difficult to say where normal variation stops and anomaly begins) are the cases where the hue of a sensation could definitely be called "queer." A number of instances were noted, however, where the sensation is distinctly "off color" for the given stimulus and background; where, for instance, the hue is one not normally seen at such eccentricity; and several others suggest that possibility. Much more frequent are cases where a colored stimulus is followed by a colorless sensation but a colored after-image. It was for these "colored after-images from subliminally colored stimuli" that we were especially on the look-out. We got them in greater numbers, perhaps, than Fernald, and certainly under more diverse conditions. They were reported, not only with

the white background under the full illumination, but with the other backgrounds, and with poor illumination, as well. The frequency was practically negligible with the black ground, but amounted, with the grey ground, to ½%, and with the white ground to 6% of the total number of tests. (Our recent tests with the black ground give added confirmation to these results): see p. 569. There were marked individual differences; the *per cent.* was highest for R and lowest for D and G. For no observer, however, was the percentage of frequency so high as in the cases where the " anomaly-inducer " was a brightness.

B. Possible Explanation

If these phenomena are not to be left in the class of anomalies, we must find some adequate and controllable cause for them in the conditions of the experiment. We must at least suggest a reasonable explanation.

1. Negative Evidence

We find ready a possible explanation for the numerous slight irregularities in the reports. The haphazard nature of the series as given, though an aid in eliminating expectation, is, evidently, not calculated for smoothness of results. The rapid change in hue during fixation, for the more peripheral points, introduces further irregularities. Suppose an observer's attention to be lagging at times; he may then easily misapprehend an intermediate stage in the transition of hue as the first hue seen and report it as such. Some of the colors, moreover, were experienced as such brief flashes that it was very difficult, as F put it, "to fix them." They must last a certain time, he said, in order to be labelled. In such cases, it is clear, a momentary lapse of attention might be fatal. There is, too, the additional difficulty that the poorer chromas are proportionately more difficult to " place " as to hue; it is obvious that a dark, poor green, for example, is much closer to yellow and blue, on the color pyramid, than is a saturated medium green.

Closely related to the difficulty of distinguishing hues, when the chroma is poor, is the difficulty of assigning names. The name " white " designates a brightness quality, that of " yellow " a color. If, in everyday experience, we have a luminous white, we may call it a " sunlight effect," and it is six of one and half a dozen of the other whether we mean to term it white or yellow. Many of the yellows and whites experienced with the white background were of this dubious sort. They were distinctly luminous, possibly as the result of the movement of

the white screen. D and G explicitly, and the other observers less so, found it difficult to make the decision, in such cases, as to color or brightness. G frequently reported, " It's white with a luminous effect " or " It's a sunlight effect." Sometimes she would decide that she ought to call it yellow, sometimes white, though she admitted that it was always the same. D, under the same stress, would make a decision at one time, and then, later, when the experience recurred, would decide that the earlier decision should be reversed. So the other observers would report " white," and often, after an interval, ask to have the record changed. Sometimes, to be sure, the change of opinion would be due to recollection of a forgotten experience; but usually it issued from a real doubt as to what to call the experience. Other experiences besides yellow gave difficulty in naming. B found it difficult, when the grey background was used, to distinguish the grey of the ground (if presented as a stimulus or used as a projection ground) from a blue-green of medium tint and extremely poor chroma. He repeatedly made this error in naming at times when there was no possibility of color adaptation. He afterwards admitted, on being questioned, that it was a common confusion for him. R and, to a less extent, F were apt to see the slightly darkened white of the projection ground, as they experienced it when somewhat adapted to it, or when it was darkened by the superposition of a colorless after-image, as a very light, poor violet or purple; they reported this experience even when all precautions were taken to secure achromatic adaptation.[10] F would sometimes say, " It's one of those cases where you'd be hanged if you know whether to report color or not." And R declared his judgments in such cases to be worthless. These hesitancies about naming make us doubtful of any reports in which they occurred.

It is evident, however, that such suggestions as are here offered would by themselves be scarcely convincing. But we find very definite evidence of the anomalous character of the reports so labelled, in the influence of the previous colored stimuli. In the cases where the hue reported is an " impossible " one, we find that it can be identified with the hue of the previous after-image. Thus, for example, F reports, with the

[10] This experience of purple or violet under apparently achromatic adaptation was provokingly frequent and insistent,—so much so that it seemed to be independent of external chromatic conditions. Prof. Titchener states that it gave trouble before in the work with the peripheral retina. Its recurrence in spite of all precautions seems to indicate that it is due to intra-ocular conditions.

grey ground, "yellow-green," when the stimulus was orange-yellow; we then find that the after-image of the preceding sensation lay between a yellow-green and a yellowish-green. Or, we have a grey reported as blue, and we find that the preceding after-image (or sensation) was blue. The reports of colored after-images with colorless sensations are to be classed, in this respect, with the reports of color with colorless stimuli. In practically all the cases (enough to make us sceptical as to the rest) we find evidence of the influence of the previous colored stimulus. It is perhaps, moreover, a significant fact that the large majority of such anomalous occurrences were reported at the beginning of the experimental hour.

2. Positive Evidence

Thus far our evidence has been mainly negative. We also sought for positive proofs. We selected influence of previous stimuli and variability of attention as controllable factors and tried (1) varying the direction of the attention and (2) varying the time-interval between tests, using in both cases the white background.

a. Change in the Direction of Attention

When the attention was on the stimulus rather than on the after-image, the number of colored after-images reported with colorless sensations was reduced, though some still occurred. When, on the other hand, the attention was directed to the after-image rather than to the sensation, the number of such anomalies was fully doubled. While these results are probably conditioned to some degree upon a central or 'subjective' factor, they are certainly due in large measure to the lapse of accommodation or the gross eye-movement which ordinarily accompanies relaxation of attention. As the method does not allow us to discriminate central and peripheral conditions, we must leave the facts in the rough, remarking only (1) that they should be borne in mind in any attempt to appraise Fernald's results, since she makes no reference to control of attention, and (2) that they are in agreement with previous results for B and R, when with the grey and white grounds respectively, under admitted unpleasant emotional distraction, the number of anomalous reports had been markedly increased.

b. Change of Interval between Tests

When the interval between tests was cut down to one minute or less, anomalies became the rule rather than the exception. An increase in the time-interval had the opposite effect. For B and F an interval of six minutes was sufficient to eliminate

them; R, who (as has been mentioned) was especially sensitive to color and adapted slowly, required, with the white ground, fully a ten-minute interval for complete achromatic adaptation; and even then he continued to report violet or purple with a white stimulus. Despite such occasional irregularities, the result of increasing the time-interval was so constant as to tell convincingly against the acceptance of these occurrences as normal.[11]

IV. Determination of Urfarben

While the work in determination of the *Urfarben* was yet in its early stages, it became evident that the present method was inadequate for exact results. The chief difficulty, aside from that of securing constant illumination, was the fact that a large number of fixation points were required. If these were much closer together than 5 degrees, steady fixation was difficult, and the results were correspondingly variable. We contented ourselves, therefore, with ascertaining that, even with adequate apparatus, the *Urfarben* would be constant only with the grey background; with the other backgrounds there is a uniform shift in a definite spectral direction. Fernald's statement that the *Urfarben* found with the grey ground hold for the black ground as well is probably due in part to the admitted hastiness of this part of her work; in part, also, to the fact (evident throughout her report) that she constantly neglected the smaller details and ignored slight changes in hue.

Conclusions

I. Critique of Method

As the result of our work with Fernald's method we are led to the following criticisms:

(1) It is an advantage, no doubt, to keep the eye stationary during the presentation of a stimulus. It is, however, a disadvantage to use a moving screen to cover the stimulus. For some observers it is a noticeable distraction; for all it may lead to a variation in conditions, since on the extreme periphery it may be more influential than nearer the center in heightening the effect of a weak stimulus.

[11] In the regular series, undertaken to test Fernald's conclusions, the anomalous after-images were, as we have said, likely to occur at the beginning of the experimental hour; not infrequently the very first observation yielded the anomalous result. In these test-series, with change of interval, a time of variable duration was allowed for preliminary achromatic adaptation; with sufficient time-allowance (up to about 10 min.) the initial anomaly disappeared.

(2) The apparatus is poorly adapted to fixations at less than 5-degree intervals from one another. For exact quantitative results it is, therefore, unreliable.

(3) The method may be improved by using, as we did, the Hering head-rest or some other like arrangement which provides for a constant position of the eye, for all fixation points, without thereby involving the slightest eye-strain.

(4) For satisfactory, reliable results, the interval between successive tests must be longer than two minutes. While this interval may be long enough for some observers, with the black background, it is certainly not enough with the white background. For highly sensitive observers, and the white background, nothing short of a 10-minute interval is adequate.

II. The Question of Anomalous After-Images

Inasmuch as it was one of the main objects of these experiments to investigate the occurrence of "colored after-images from subliminally colored stimuli," it may be well to give in some detail a summary of our conclusions.

(1) The frequency of these anomalous colored after-images was considerably less than that for like anomalies with colorless stimuli.

(2) Previous stimuli were found to influence the hue of succeeding sensations, as well as of succeeding after-images.

(3) Colors were seen during the fore-period of tests, after an interval of over two minutes.

(4) The number of anomalous after-images was increased when the attention to them was greater than to the corresponding sensation; the number was decreased when the attention was predominantly directed to the stimulus. We attribute this result, in the main, to changes of accommodation and to eye-movement.

(5) The frequency of their occurrence was increased as the interval between the tests was shortened, and was correspondingly decreased as the interval was increased. *An interval of ten minutes was found adequate, with the white background, for the most sensitive observer, to eliminate entirely such anomalies.* They had occurred in 6% of the observations of our regular series.

(6) Anomalous after-images occur, on the average for all observers, in only ½% of our regular observations with the grey background, and with negligible frequency when the black background was employed.

III. General Summary

A. The medium grey background gives us a standard account of the changes which color phenomena with the ten colored stimuli undergo, from the fovea to the periphery. We find that: (*a*) the sensations from: (1) red, orange, orange-yellow, yellow, yellow-green and green stimuli, shift toward or to yellow; while (2) blue-green, blue, violet, and purple stimuli, shift toward or to blue; and (*b*) the after-images from: (1) red, orange, orange-yellow, yellow, yellow-green, and green stimuli, shift toward or to blue; while (2) blue-green, blue, violet, and purple stimuli, shift toward or to yellow. The change in hue of the after-image is always such that the after-image is the complement of the sensation.

B. 1, Whenever the sensations or after-images are darkened, by (1) contrast with the white background, (2) the mixture of black with the stimuli, (3) the superposition of dark after-images on the sensations, (4) the projection of the after-images on a dark ground, or (5) the projection of after-images, already in course, on a light ground; then, always, there is a shift in hue in the direction of the red end of the spectrum.

2. Whenever the sensations or after-images are lightened by any of these five means, then, always, there is a shift in hue in the direction of the violet end of the spectrum.

C. Sensations and after-images have been found to change in hue during fixation. With the grey ground: (1) the sensations from orange, orange-yellow, yellow, yellow-green, green, and blue-green shift toward yellow; those from blue, violet, purple, and red shift toward red; (2) the after-images of red, orange, orange-yellow, yellow, and yellow-green shift toward green; those from green, blue-green, blue, violet, and purple shift toward green in the other direction. With the black ground, sensations and after-images from red, orange, orange-yellow, yellow, and yellow-green shift toward violet, those from green, blue-green, blue, violet and purple shift toward red, in comparison with those on the grey ground. The spectral direction is exactly the opposite with the white ground.

D. Different types of color sensation and after-image have been found. In the case of the sensation: (1) the 'flash" type occurs chiefly with the white ground at the more peripheral points; (2) the "persistent" type is found at all other points. As regards the after-images: (1) the "flash" type

occurs most frequently with the black background on the periphery; (2) the "persistent" type occurs most often with the white and grey grounds; (3) the "double" type, never frequent, is most often reported with the black ground; (4) colorless after-images are most frequent with the black background and least with the grey. It seems probable that the "persistent" type is the normal form for both sensation and after-image, and that the "flash" type, whether it occurs alone or as a member of the "double" type, is the result of the heightening of a liminal (or even subliminal) stimulus by movement of the screen across the field.

IV. Theoretical Discussion

Our results with the grey background are in agreement with the requirements of the Hering theory. The work with the black and white backgrounds, and with colors mixed with black or white as stimuli, indicate that: (1) the additional stimulation of the black process, with that for a given color, results always in a shift toward the red end of the spectrum; (2) the additional stimulation of the white process results in a shift toward the violet end of the spectrum; the amount of shift increases with an increase in the black-white process, until the color, already poor in chroma, becomes so dark or so light that it passes below the limen. Whether this result means that other color processes are actually stimulated, we cannot say. Nor can we say whether it means merely that certain brightnesses heighten the stimulating effect for certain colors, already physically present in the stimulus, at the expense of other colors also present. This question could be answered only by using physically pure stimuli, or those whose physical components were known. The problem presents no greater difficulties than does the mixture of black or white with colors seen at the fovea.

The shift in hue of sensations and after-images during fixation seems to indicate a greater instability of the peripheral retinal processes.